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onsingular Black Hole Evaporation and "Stable" Remnar

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We examine the evaporation of two–dimensional black holes, the classical space–times of which are extended geometries, like for example the two–dimensional section of the extremal Reissner–Nordstrom black hole. We find that the evaporation in two particular models proceeds to a stable end–point. This should represent the generic behavior of a certain class of two–dimensional dilaton–gravity models. There are two distinct regimes depending on whether the back–reaction is weak or strong in a certain sense. When the back–reaction is weak, evaporation proceeds via an adiabatic evolution, whereas for strong back–reaction, the decay proceeds in a somewhat surprising manner. Although information loss is inevitable in these models at the semi–classical level, it is rather benign, in that the information is stored in another asymptotic region.

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1. Introduction

One of the authors (M.O'L.) and T.Banks [1] had previously proposed that for a large class of modified scalar-gravity theories in which the classical geometries are all nonsingular, with causal structure identical to that of Reissner–Nordstrom, the Hawking evaporation to a final zero temperature remnant–like object could be studied without singularity, as opposed to the original CGHS (Callan-Giddings-Harvey-Strominger) [2] models in which a now well known singularity was found.

Here we report on calculations that support this picture. When in–falling matter perturbs one of these extremal solutions, two apparent horizons form. As the evaporation takes place, these apparent horizons approach each other. We find two distinct regimes, depending on whether the back–reaction is weak or strong in a certain sense. With weak back–reaction, an adiabatic approximation gives a correct description, and things settle back down to a stable remnant, with the apparent horizons meeting only after an *infinite* proper time. In the strong back–reaction regime, the apparent horizons meet after a *finite* proper time, and only after meeting do things settle back down to the extremal solution. Black holes in these models therefore evaporate in a completely nonsingular fashion, realizing the original objectives of CGHS. Information loss occurs at the semi–classical level, but only in a rather benign way.

In section 2 we introduce the models of interest. We discuss in some detail the behavior near the double horizon of the extremal static semi–classical space–time in section 3. In section 4 we describe the adiabatic approximation [3] for the nonsingular models. Section 5 contains the results of our numerical analysis and section 6 is devoted to our conclusions and a discussion of their implications.

2. The Models

Consider a Lagrangian taken from the general class of two–dimensional renormalizable generally covariant field theories [4],

$$\mathcal{L}_{cl} = \sqrt{-g}(D(\phi)R + G(\phi)(\nabla\phi)^2 + H(\phi)) \ . \tag{2.1}$$

We require that the potentials behave asymptotically like those of linear dilaton gravity [2],

$$D(\phi) \to \frac{G(\phi)}{4} \to \frac{H(\phi)}{4} \to e^{-2\phi} \ , \tag{2.2}$$

as $\phi \to -\infty$.

The renormalization group equations are hyperbolic on the two–dimensional target space of this model, and thus given a set of initial data one can consistently renormalize the model [5]. In the following, without loss of generality, we will restrict attention to the class of models satisfying $G(\phi) = -2D'(\phi)$. Other models may be obtained by a field redefinition of ϕ. Performing a Brans–Dicke transformation on the metric $\hat{g} = e^{-2\phi}g$ this Lagrangian may be rewritten in the simple form

$$\hat{\mathcal{L}}_{cl} = \sqrt{-\hat{g}}(D(\phi)\hat{R} + W(\phi)) \tag{2.3}$$

where we have defined $W(\phi) = e^{2\phi}H(\phi)$. This form of the Lagrangian is convenient for finding the classical solutions as described in [1] , in which reference the extended space–time geometries are discussed.

All solutions are causally related to the two–dimensional $r - t$ section of the four–dimensional Reissner–Nordstrom (RN) black hole (see fig. 1 for the extremal geometry), but as noted above, the geometries in these generalized models may be nonsingular. The nonsingularity is achieved by requiring that as $\phi \to \infty$, $D \sim e^{n\phi}$ and $W \sim e^{m\phi}$, such that